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Review

A Systematic Review of the Validity of Dietary Assessment Methods in Children when Compared with the Method of Doubly Labeled Water

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ABSTRACT

Measuring dietary intake in children enables the assessment of nutritional adequacy of individuals and groups and can provide information about nutrients, including energy, food, and eating habits. The aim of this review was to determine which dietary assessment method(s) provide a valid and accurate estimate of energy intake by comparison with the gold standard measure, doubly labeled water (DLW). English-language articles published between 1973 and 2009 and available from common nutrition databases were retrieved. Studies were included if the subjects were children birth to age 18 years and used the DLW technique to validate reported energy intake by any other dietary assessment method. The review identified 15 cross-sectional studies, with a variety of comparative dietary assessment methods. These included a total of 664 children, with the majority having <30 participants. The majority of dietary assessment method validation studies indicated a degree of misreporting, with only eight studies identifying this to a significant level ($P<0.05$) compared to DLW estimated energy intake. Under-reporting by food records varied from 19% to 41% (n=5 studies) with over-reporting most often associated with 24-hour recalls (7% to 11%, n=4), diet history (9% to 14%, n=3), and food frequency questionnaires (2% to 59%, n=2). This review suggested that the 24-hour multiple pass recall conducted over at least a 3-day period that includes weekdays and weekend days and uses parents as proxy reporters is the most accurate method to estimate total energy intake in children aged 4 to 11 years, compared to total energy expenditure measured by DLW. Weighed food records provided the best estimate for younger children aged 0.5 to 4 years, whereas the diet history provided better estimates for adolescents aged ≥16 years. Further research is needed in this area to substantiate findings and improve estimates of total energy expenditure in children and adolescents.

J Am Diet Assoc. 2010;110:1501-1510.

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Manuscript accepted: April 30, 2010.

0002-8223/$36.00
doi: 10.1016/j.jada.2010.07.008

Accurate assessment of child and adolescent food intake is an important factor in determining the nutritional adequacy of an individual child's diet. Previous research suggests that collecting reliable and accurate dietary data from this population group can be difficult (1).

Parents are often used as proxy reporters of their children's dietary intake in research studies (2). This is largely due to children at younger ages having lower literacy levels, limited cognitive abilities, and difficulties in estimating portion size (2). It has been previously acknowledged that children younger than approximately 8 years old cannot accurately recall foods, estimate portion size, and cannot conceptualize frequency of food consumption (2). However, as a child grows older and develops cognitively, the ability to self-report his or her own food intake improves (1). The age at which a child becomes an accurate self-reporter of his own dietary intake has been estimated to be approximately 12 years, although this varies by dietary assessment method (1).

The literature suggests that there is a transition period between the ages of 8 and 12 years, during which a child becomes a more accurate reporter of his own dietary intake. There is no consistency in terms of whether the parent or child was the reporter of child intake in previous studies, nor have recommendations been based on who is the most appropriate reporter of dietary intake for children in this age range. These issues have been discussed in a recent review (3).

Validity refers to the ability of a dietary assessment tool to measure food consumption data that represents the true dietary intake of the individual (1). A method is described as valid if reported dietary intake is not significantly different to actual dietary intake consumed (1). Valid dietary assessment methods are needed to measure and then compare the data reported by parent and child to determine who is the most accurate reporter. There are limited validated dietary assessment tools for use with pediatric populations (1), and no published studies to date were identified that had investigated parent and child report against an objective measure of dietary intake within in the same study.

It is common for dietary assessment tools to be compared or validated against another similar method (1) or by direct observation of meal consumption (4-6). This technique is limited in that the comparative method is subject to similar limitations as the tool being assessed. The majority of dietary assessment methods are subject to recall bias, as they rely on a participant's memory (7). To overcome this, an objective measure that is independent of error in the method being evaluated is desirable to assess the validity of a dietary assessment tool so that correlation does not occur on the basis of statistical errors that are common to both approaches.

Doubly labeled water (DLW) is considered to be the gold standard reference method for validation of measurements of energy intake (EI). DLW estimates total energy expenditure (TEE) and is typically measured over a period of 7 to 14 days and incorporates short-term day-to-day variation in physical activity (8,9). However, even a 14-day period cannot account for seasonal variation in physical activity levels or other situations that affect energy expenditure with time. A review that included both children and adults aged 6 to 74 years demonstrated the coefficient of variation for repeated measurements of energy expenditure by DLW is 8% to 10% (9). In free-living, weight-stable individuals TEE as measured by DLW is reflective of actual EI (10). This makes it possible to determine the accuracy of reported EI. The DLW method is seldom used due to the high costs, moderate participant research burden, and the high technical skills and facilities required for analysis.

In this review, studies intending to validate dietary assessment tools for the measurement of EI in children were considered. The aim of this review was to evaluate the accuracy of dietary assessment methods used to estimate the daily EI of children by comparing reported intake with TEE measured by DLW.

METHODS

The review was conducted in three stages:

In Stage 1, articles were retrieved via on-line database searching, hand-searching reference lists, and cited reference searches (Figure). The online databases of Cumulative Index to Nursing and Allied Health Literature, Cochrane, MEDLINE, ProQuest, PubMed and Excerpta Medica Database were searched. Keywords and combinations of these were used to search the databases comprehensively. The keywords included child, adolescent, paediatric (pediatric), dietary assessment, food frequency questionnaire, dietary recall, diet record, energy intake, energy expenditure, doubly labeled (labeled) water, and validation. Articles were limited to those printed in English-language journals between 1973 and January 2009. The reference lists of articles retrieved for inclusion in the review were hand-searched to identify other relevant articles. Key articles retrieved via online databases and hand-searching reference lists were also used for further searches using the Web of Science database Cited Reference function. The results of Cited Reference searches were narrowed using the key words child; adolescent and paediatric (pediatric); doubly labeled (labeled) water; and validation. This was undertaken to capture the most relevant articles for further evaluation and critical appraisal.

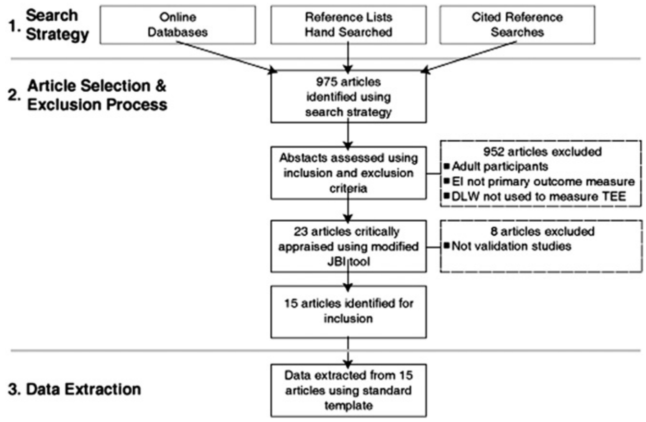

Figure. Flow chart of method of determining studies to be included in the review of evaluating dietary methods against the gold standard doubly labeled water method.

During Stage 2, the titles and abstracts of articles were reviewed to assess eligibility for inclusion in this review. Articles were identified as relevant to the review if they were experimental studies aiming to compare reported dietary intake with TEE, if they included child and/or adolescent participants (aged <18 years), reported EI as measured by a dietary assessment tool, used DLW to estimate TEE, and the primary purpose of the study was validation of the dietary assessment method. Studies were included regardless of the reporter of the child's dietary intake (parent or child reported data). If it was not clear if an article should be included from the review of the abstract, the full article was retrieved.

In Stage 3, all retrieved articles were independently assessed for quality, using a standardized quality assessment checklist (11) and one reviewer (R.J.M.) critically appraised the articles using the Joanna Briggs Institute critical appraisal tool to identify sources of bias, performance, attrition, and detection (12). Data relevant to this review included the study design, characteristics of participants, dietary method/s used, and results.

Methods to Determine Accuracy

The reporting status of the dietary intakes in each of the included studies was determined from either that listed within the results section of the included article or for those studies where this was not listed was calculated as EI/TEE.

The reporting status of each study was determined using three predefined categories consistent with previous definitions (13). The categories are dependent on the level of accuracy of reported EI compared to measured TEE. These three categories included: adequate reporters' (EI/TEE within the 95% confidence limits 0.84 to 1.16), under-reporters (EI/TEE <0.84), or over-reporters (EI/TEE >1.16). Where available from included studies, results were extracted if the reporting status of participants was correlated to various characteristics of the group. These characteristics include demographic statistics (age and sex), anthropometric characteristics (height, weight, and body mass index), and body composition statistics (percentage body fat and fat-free mass). Limitations of each study and the evidence level (14) were also recorded.

Limits of agreement (LOA) were commonly reported using the Bland-Altman approach (11 studies). With this method, a pairwise comparison is used to assess the relative bias (mean difference ±2 standard deviations) between the estimated EI and the reference measure of TEE. The calculation of the mean difference provides information about the direction and magnitude of bias and whether the bias is constant across levels of intake. When the limits of agreement are approximately equal to two standard deviations of the mean difference, then the two methods are considered to be in fairly good agreement. Consequently, LOA are reported as megajoules (MJ)/day or kilojoules per day. The LOA is often used to provide additional data to characterize the validity, or otherwise, of the comparative EI estimate assessment (15). For example, the level of agreement between EI reported by 24-hour recall and TEE by DLW would be determined by plotting the individual differences between each of the methods for each participant then calculating the mean difference and standard deviation. If the values fall outside the two standard of deviation limit of agreement, this would indicate a poor level of agreement, on an individual level.

RESULTS

A total of 975 articles were identified using the search strategy outlined in the Figure. Of these, 23 were retrieved for quality checking and critical appraisal. The critical appraisal process resulted in the inclusion of 15 articles, for this review, all with a positive study quality when assessed against pre-specified criteria (11). The main reasons for exclusion included adult studies, EI not reported, and DLW not used to measure TEE. All studies included were cross-sectional in design and were classified as Level IV evidence (14). Table 1 outlines a summary of the participants, dietary assessment methods, DLW reporting period, dosage amounts, number of collection days of urine samples, and provides indication of body weight assessment for each study. In terms of reporting body weight, eight of the15 studies reported that participant body weights were measured at baseline only, six studies measured both pre and post body weights with one study reporting a significant increase in weight over the collection period. Only one study did not report whether body weight had been measured. All studies included a urine collection predose of DLW.

A total of 780 children and adolescents participated across the 15 studies; however, only 664 of these had data recorded for TEE measured by DLW, in addition to reported EI. This review only includes the data for participants with both TEE and EI data recorded.

All studies included participants who were reported to be free-living individuals. The age of participants ranged between 0.5 and 18 years with the majority (n=9) of studies being carried out in children aged 4 to 11 years with limited studies at the lower (n=3) and upper ends of the range (n=3). Studies were largely carried out using white children. Of the 15 studies, three studies included children from a range of ethnicities, including African-American children (16-18) and two studies were identified that were carried out with overweight/obese participants (19,20). The majority of studies (11 of 15) used a single dietary assessment method to estimate dietary energy intake, whereas three studies used two separate dietary intake methods (18,21,22).

Table 2 provides a detailed description of the included studies and their limits of agreement, where reported. Table 3 displays the characteristics of participants identified as misreporters, as per the criteria detailed in methods section.

Twenty-four–hour multiple pass recalls (MPRs) (n=4 studies) (18,23-25) and estimated food records (EFR) (n=5) (18,19,21,23-28) were the single most commonly used dietary assessment tools. Diet history methods (13,20,22) used in three studies and weighed food records (WFRs) (21,22,29) and food frequency questionnaires (FFQs) (each FFQ with a reporting period of the previous 12 months) were used to estimate EI in two studies each (17,30). One study measured energy intake using a combination of both WFRs and EFRs (31), and dietary intake was verbally recorded on tape in one study (18). In each of the studies, the 24-hour MPR was conducted using a three-pass method, which included a quick list, detailed description review, and use of either food models/portion photographs or household measures for each of three separate days. The average value of the recalls was used to compare with TEE by the DLW method.

All studies assessed energy intake using a particular dietary method assessed within the same time period as the DLW collection. In all studies, participants were instructed to report usual dietary intakes for WFR, EFR, and 24-hour MPR in an attempt to capture intake representative of both weekdays and weekends.

Dietary intake was most commonly reported by both the child and one or two parents/caregivers (seven out of 15 studies) (17,20,22,23,26,27,30). Five studies reported obtaining dietary intake data from parents only (21,22,24,25,29) and four studies used child reported data alone (13,18,19,31). Parents were more likely to report the child's intake for them when the child was young (younger than age 7 years in four studies [21,24,25,29] and younger than 9 years in one study [22]) or when the dietary assessment method required a greater level of skill or was an increased burden on participants (eg, parents recorded weighed foods for children up to age 9 years [22]). In all studies where parents were used to report their child's intake, mothers were used as the main reporters. Fathers were reportedly used occasionally in only two studies (23,32). Older children and adolescents were more likely to report their own intake (participants aged 12 years or older in three studies [13,19,31], aged 6 to 11 years in one study [18]) and a combination of parent–child reports were used over a range of ages (see Table 1).

Energy intake was estimated from reported dietary intake in all 15 studies using food composition tables and nutrient analysis software in 11 studies (18,20-27,29,31). Four studies did not report the methods used for analysis and calculation of EI (13,17,19,30).

Across the 15 studies reviewed, all dietary methods

Table 1. Cross-sectional studies identified in a systematic review of the validity of dietary assessment methods used in children (0 to 18 years) when compared with the method of doubly labeled water (DLW)

Author(s) and country	n	Sex	Age (y) Range	Age (y) Mean±SD[a]	Subjects Mean±SD	Dietary recall method and reporting period	Reporter	Length of DLW collection (d)	No. of urine samples	Dosage	Weight collected pre and post study?
24-h multiple pass recall (MPR)											
Johnson and colleagues (23) USA	24	Boys (n= 12) Girls (n=12)	4-7	Boys 6.4±1.0 Girls 5.5±0.7	White BMI[b]: Boys 18±3.1, Girls 17.9±2.7	24-h MPR 3 d	Parent+child	14	5	0.12 g ^2H_2O and 0.15 g $H_2{}^{18}O$/kg body weight	Yes
Reilly and colleagues (25) Scotland	41	Boys (n=18) Girls (n=23)	3-4	3.7±0.4	BMI 16.1±1.8	24-h MPR 3 d	Parent	7	3	0.06 mL ^2H_2O and 1.6 mL $H_2{}^{18}O$/kg body weight	Baseline only
Lindquist and colleagues (18) USA	30	Boys (n=17) Girls (n=13)	6.5-11.6	9.5±1.4	African American (n=13) White (n=17) BMI 20.9±5.8	24-h MPR 3 d + Tape recorded 3 d	Child	14	5	0.12 g ^2H_2O and 0.15 g $H_2{}^{18}O$/kg body weight	Baseline only
Montgomery and colleagues (24) Scotland	63	Boys (n=32) Girls (n=31)	4.5-7	Boys median 6.0 (4.8-6.7) Girls median 5.7 (4.5-6.9)	BMI: Boys median 16.25 (13.5-21.5), Girls 15.4 (14-20.5)	24-h MPR 3 d	Parent	10	3	0.24 mL ^2H_2O and 1.6 mL $H_2{}^{18}O$/kg body weight	Baseline only
Diet history interview (DHI)											
Sjoberg and colleagues (13) Sweden	35	Boys (n=18) Girls (n=17)	15-17	15.7±0.4	BMI 20.7±2.5	DHI (questionnaire+ interview)	Child	15	8	0.05 g ^2H_2O and 0.10 g $H_2{}^{18}O$ kg body weight	Yes
Waling and Larsson (32) Sweden	21	Boys (n=10) Girls (n=11)	8.3-12.4	10.5±1.1	Overweight (n=16) Obese (n=5) BMI 23.1± 2.6	DHI	Parent+child	14	6	0.12 g ^2H_2O and 0.25 g $H_2{}^{18}O$/kg estimated total body water	Yes
Livingstone and colleagues (22) UK	78	Boys (n=41) Girls (n=37)	3-18		3 y (n= 8) 5 y (n= 12) 7 y (n= 12) 9 y (n= 12) 12 y (n= 12) 15 y (n= 12) 18 y (n= 10)	DHI	Parent for children 3-5 y Parent+child for 7-18 y	10-14 d depending on age	11-15 depending on age	0.05 g ^2H_2O and 0.125 g $H_2{}^{18}O$/kg body weight	Baseline only
Estimated food record (EFR)											
O'Connor and colleagues (26) Australia	47	Boys (n=22) Girls (n=25)	6-9	7.4±0.8	BMI 16.8±2.3	EFR	Parent+child	10	12	0.05 g ^2H_2O and 0.125 g $H_2{}^{18}O$/kg body weight	Baseline only
Lanigan and colleagues (21) UK	21	Boys Girls	6-12 mo	8.1±1.6 mo	Weight 9.2±1.2 kg	EFR 5 d WFR 5 d Cross-over design	Parent	7	7	—	Baseline only
Bandini and colleagues (19) USA	55	Boys 28 Girls 27	12-18	14.4±2.0	Obese (n= 28) Weight 95±25.1 kg Height 163.9±7.6 cm Nonobese (n=27) Weight 56±9.6 kg Height 164.4±8.5 cm	EFR 14 d	Child	14	4	0.1 g^2H_2O and 0.25 g $H_2{}^{18}O$/kg estimated total body water	Yes
Champagne and colleagues (33) USA	23	Boys (n=12) Girls (n=11)	11.1-11.7		African American (n= 11) BMI 21.3±2.2 White (n= 12) BMI 19.3±2.0	EFR 8 d	Parent+child	9	4	0.14 g ^2H_2O and 0.25 g $H_2{}^{18}O$/kg total body water	Baseline only
Bratteby and colleagues (31) Sweden	50	Boys (n=25) Girls (n=25)		15 y	Boys BMI 20.2±2.8 Girls 20.9±2.5	EFR 7 d	Child	14	17	0.15 g ^2H_2O and 0.3 g $H_2{}^{18}O$/kg total body water	Yes
Food frequency questionnaire (FFQ)											
Perks and colleagues (30) USA	50	Boys (n=23) Girls (n=27)	8.6-16.2		BMI 19.5±3.3	FFQ Reporting period 1 y	Child	12	6	0.05 g ^2H_2O and 1.5 g $H_2{}^{18}O$/kg body weight	Baseline only
Kaskoun and colleagues (17) USA	45	Boys (n=22) Girls (n=23)	4.2-6.9		White (n= 36) Native American (n= 9) Boys weight 19.5±4.1 kg, height 1.11± 0.1 cm Girls weight 20.7±4.1 kg, height 1.12±0.1 cm	FFQ Reporting period 1 y	Parent	14	5	≈ 0.12 g ^2H_2O and 0.15g $H_2{}^{18}O$/ kg body weight	Yes

(continued)

Table 1. Cross-sectional studies identified in a systematic review of the validity of dietary assessment methods used in children (0 to 18 years) when compared with the method of doubly labeled water (DLW) (continued)

Author(s) and country	n	Sex	Age (y) Range	Age (y) Mean±SD[a]	Subjects Mean±SD	Dietary recall method and reporting period	Reporter	Length of DLW collection (d)	No. of urine samples	Dosage	Weight collected pre and post study?
Weighed food record (WFR)											
Davies and Coward (29) UK	81	Boys (n=40) Girls[c] (n=40)	1.5-4.5		Age groups 1.50-2.49 (n=23) 2.50-3.49 (n= 31) 3.5-4.49 (n=27)	WFR 4 d	Parent	10	11	0.05 g ^2H_2O and 0.125 g $H_2{}^{18}O$/kg body weight	N/S[d]
Livingstone and colleagues (22) UK	58	M + F	7-18		3 y (n=8) 5 y (n=12) 7 y (n=12) 9 y (n=12) 12 y (n=12) 15 y (n=12) 18 y (n=10)	WFR 7 d	Parents of children 7-9 y Child 12-18 y	10-14 d depending on age	11-15 depending on age	0.05 g ^2H_2O and 0.125 g $H_2{}^{18}O$/kg body weight	Baseline only

[a]SD=standard deviation.
[b]BMI=body mass index.
[c]Exact numbers not reported; article indicates approximately equal numbers of boys and girls.
[d]NS=not specified.

produced some degree of misreporting. Significant underreporting of EI was found for EFRs (19% to 41% of estimated EI, n=3 of five studies), WFRs (11% to 27%, n=1 of two studies) and over-reporting for multiple 24-hour MPR recall (7% to 11%, n=2 of four studies) and FFQs (up to 59%, n=1 of two studies).

Sex, weight status, and ethnicity are indicated where reported in included studies. Reporting status was categorized by sex in five studies. Underreporting was found in both girls (three out of five studies [13,20,21]) and boys (two out of three studies [20,31]). Misreporting associated with sex was not related specifically to any dietary assessment method or the reporter of intake. Two studies examined the relationship between weight status and misreporting (19,20). Both studies found that EI was underreported in overweight and obese children. Waling and colleagues (32) reported that obese children were twice as likely to under-report compared to overweight children, whereas Bandini and colleagues (19) found that they twice as likely to under-report compared to nonobese children. Interestingly, in four other studies included, the likelihood of under-reporting was most strongly predicted by higher percent body fat (28,30), reported total grams of dietary fat (26), or by individuals in the highest tertile of body fat (33). In one study, African-American participants under-reported their intake by 37% less than measured TEE, which was significantly different to white participants (reported EI 13% less than TEE as measured by DLW).

The majority of studies reported that the dietary assessment method used had provided a good estimate of EI at the group level. However, at the individual level, the accuracy was reduced. The mean reported EI and mean TEE as measured by the DLW at the group level were not significantly different in many studies; however, the wide LOA indicate that large variations occurred at the individual level. Five studies concluded that the method used for dietary assessment could not be used for assessment of group or individual EIs (17-20,27).

DISCUSSION

Analysis and Discussion of Results

This review identified only 15 studies that have evaluated the accuracy of dietary assessment methods used to estimate the daily EI of children by comparing reported intake with TEE measured by DLW.

Although all studies were associated with a degree of misreporting, the diet history method demonstrated variation with two of the three studies identifying underreporting (14% to 18%) and the third study finding over-report (6-14%). Eight studies identified misreporting of intake to be statistically significant to TEE as measured by DLW (17-20,22,24,25,31). The misreporting of dietary intake by dietary assessment method showed that only participants who reported using the diet history (plus interview) method did not misreport intake significantly. However it should be noted that this was only a single study with a small sample size (n=35 participants), limiting the generalizability of this finding (13).

Approximately half of all child participants who had their EI recorded using 24-hour MPR and diet history (interview only) were found to significantly over-report

Table 2. Results and outcomes of dietary validation studies included in a systematic review of the validity of dietary assessment methods used in children (0 to 18 years) when compared with the method of doubly labeled water (DLW)

Author(s)	Diet recall method (d)	Results	Significance of results	LOA[a]	Limitations
24-h Multiple pass recall (MPR)					
Johnson and colleagues (23)	24 MPR 3 d	NS[b] between mean 24-h MPR and mean TEE Mean difference EI UR[c] by 3% NS between sexes No correlation between EI and TEE thus 24-h MPR	The 24-h MPR is useful for estimating group intake of EI of children 4-7 y reported by parents	1.10, 807 kcal/d	• Recall bias • Wide LOA • Only 3 d data collection • Small sample size
Reilly and colleagues (25)	24 MPR 3 d	EI significantly ($P<0.001$) OR[d] by 11% mean 660 kJ 95% CI (183-1,137) NS between sexes No relationship to weight status	The 24-h MPR produced a significant over estimate of children 3-4 y	660±3,018 kJ/d	• Recall bias • Wide LOA • Only 3 d data collection • Portion sizes used based on adult serve sizes
Lindquist and colleagues (18)	24 MPR 3 d+tape recorded	24-h MPR NS between TEE and recall for group or ethnicity No sex difference (Mean 0.04 MJ[e]/d) Taped significantly ($P<0.05$) UR by 14% (−1.13 MJ/d) and remained significant for African-American children (−2.44 MJ/d). Misreporting association with older age and greater adiposity.	Traditional recall method more accurate for reported EI than tape recorded	LOA not reported	• No LOA reported • Participants weight at the end of the study unknown • Diet intake were completed at various times throughout year to capture seasonality
Montgomery and colleagues (24)	24 MPR 3 d	NS between mean EI and mean TEE for boys EI significantly ($P<0.05$) OR by 7% for girls median difference 440 kJ/d	The 24-h MPR OR EI in children 4-7 y	−2.88, 2.38 MJ/d	• Results not reported for total group • Recall bias • Adult portion sizes used • Wide LOA
Diet history interview (DHI)					
Sjoberg and colleagues (13)	DH+	NS between mean EI and mean TEE for total group (4% UR) Girls 18% UR ($P<0.001$) but not for boys (8% UR) Weight changed significantly ($P=0.02$) between start and finish time of study for boys (+0.82±1.39 kg) but not girls	DH+ method used is valid to assess habitual intake or ranking of individuals for adolescents with reporting accuracy related to sex	−5.63, −6.45 MJ	• Wide LOA • Weight change of participants may confound the TEE calculated from the DLW • Relies on participants memory
Waling and Larsson (20)	DHI	EI UR by 14% (1.66±1.76 MJ/d when compared to TEE by DLW Both boys + girls significantly ($P<0.05$) UR 17% & 11%, respectively. The level of underestimation did not differ between sexes NS between weight categories EI UR by 22% by obese which is twice the rate for overweight. UR negatively correlated with body mass index (−0.38, $P<0.01$)	The DH method UR dietary intake compared with measured TEE. The reported EI of children with a higher body mass index and were older UR more than children with lower body mass index and younger	−0.1, 3.42 MJ/d	• Small sample size • Wide LOA
Livingstone and colleagues (22)	DHI	EI significantly ($P<0.05$) OR by 13.9% for children 3 y, 6.1% 9 y, 13.7% 12 y, mean difference 0.45 MJ/d In 15 y good agreement 18 y small bias to UR −2%±21% (NS)	Better agreement than the comparable weighed diet records in this study DHI are biased toward over estimation and lacked precision at individual assessments	−3.07, 3.98 MJ/d	• Weight of participants over duration of study not measured; small sample when divided into age groups
Estimated food record (EFR)					
O'Connor and colleagues (26)	EFR 3 d	NS between mean EI and TEE, difference approx 4% (118±1,706 kJ/d) Biggest predictor of misreporting was reported fat grams.	EFR suitable for nutrition assessment of EI children 6-9 y	−3.23, 3.46 MJ/d	• Wide LOA • EFR may not be representative only 3-d recorded data • Relies on participant's memory
Lanigan and colleagues (21)	EFR and WFR each 5 d	No significant diff between mean EI and metabolizable energy from either dietary method. EFR and WFR OR EI by ≈7.3% (238 kJ/d) and (243 kJ/d), respectively	EFR are a reasonable measure of young children's intake (6-24 mo)	243±1,690 kJ/d	• Wide LOA • DLW used to calculate metabolizable energy and not TEE so not directly comparable with other studies

(continued)

Table 2. Results and outcomes of dietary validation studies included in a systematic review of the validity of dietary assessment methods used in children (0 to 18 years) when compared with the method of doubly labeled water (DLW) (continued)

Author(s)	Diet recall method (d)	Results	Significance of results	LOA[a]	Limitations
Bandini and colleagues (19)	EFR 14 d	Mean reported energy was significantly ($P<0.001$) UR by the whole group with obese individuals UR more, 41.3% compared to TEE. Non obese UR by 19.4% No differences between sexes Mean weight change over the study was 0.15±1.29% in nonobese group and 0.31±1.02% in obese (NS)	EFR over a 2-wk period did not reliably predict EE in obese and nonobese individuals. Recording errors may increase with body size	LOA not reported	• Participants showed small amount of weight change • Participants paid for research • LOA not reported
Champagne and colleagues (16)	EFR 8 d	African-American children significantly ($P=0.002$) UR 37% (950±200 kcal) white UR 13% ($P=0.06$) (320±160 kcal) Children in the highest tertiles of body fat were more likely to UR	EI is UR when using dietary records to establish nutrient intake. African-American children may be more likely to UR	LOA not reported	• Participants weight at the completion of the study not reported
Bratteby and colleagues (31)	EFR 7 d	Both boys (18.1%) and girls (21.7%) significantly ($P<0.05$) UR EI UR was associated with increased percent body fat and weight	EIs UR in adolescents using the 7-d diet record particularly those with a tendency toward overweight and increased body fat content	LOA not reported	• LOA not reported • Results not reported as whole group only by sex
Food frequency questionnaire (FFQ)					
Perks and colleagues (30)	FFQ Previous 12 mo	Equal numbers of participants OR (6.65 MJ/d) and UR (6.39 MJ/d) when EI compared to TEE however differences were not significant Boys and girls were significantly more likely ($r=-0.25$) to UR as percent body fat increased	FFQ good means of estimating EI however wide LOA indicate not good at individual level	−6.30, 6.67 MJ/d	• FFQ has reporting period of 1 y so not directly reflecting the DLW collection period • FFQ reliant on memory
Kaskoun and colleagues (17)	FFQ Previous 12 mo	Significant ($P<0.001$) difference between mean EI and TEE, OR 59% (3.39±2.45 MJ/d). Girls significantly OR 62%, boys significantly OR 56% NS between sex or ethnicity	FFQ overestimates EI in children 4-6 y in white and native American children	−1.58, 9.57 MJ/d	• FFQ has reporting period of 1 y so not directly reflecting the DLW collection period • FFQ uses adult portion size
Weighed food records (WFR)					
Davies and Coward (29)	WFR 4 d	NS between EI and TEE, the average difference was 3% (154 kJ/d). Older children 3.5-4.5 y mean difference 37 kJ/d	Weighed food intake methodology can provide accurate population-based data for children 1.5-4.5 y	−3.5, 1.8 MJ/d	• Eating habits may be influenced due to burden of WFR • Participants weight at the end of the study unknown
Livingstone and colleagues (22)	WFR 7 d	WFR good agreement for children 7-9 y EI significantly ($P<0.001$) UR by 11% in 12 y, 22% 15 y 27% in 18 y Mean difference −1.47 (−2.24, 0.70 MJ/d)	The weighed diet record has a bias toward underestimating EI in adolescents	−7.31, 4.37 MJ/d	• Wide LOA • As above

[a]LOA=limits of agreement. The limits of agreement presented indicate the mean difference between the estimated energy intake (EI) and the reference measure of total energy expenditure (TEE) by DLW±2 standard deviations.
[b]NS=no significance difference.
[c]UR=under report.
[d]OR=over report.
[e]MJ=megajoules.

their intake. However both 24-hour MPR and diet history interview produced more modest over-reports of dietary intake than other methods (9% and 12.6% over-report respectively). Over-reporting using 24-hour MPR and diet history interview was found to be significant when dietary intake was reported by parents (three out of five studies used parents only [22,24,25], another two used parent-child reports [20,22], as shown in Table 1).

EFRs produced a significant underestimation of EI (30.4% less than TEE); however, two other studies that used EFR to measure dietary intake did not demonstrate significant misreporting—one carried out in young children aged 0.5 to 1 year with 10 participants and the other with 47 children aged 6 to 9 years (21,26). In addition to these, one study did not report statistical findings from their results (27). Bandini and colleagues (19) collected dietary data from older children aged 12 to 18 years over a 14-day collection period that may have contributed to misreporting of intake due to the high burden placed on participants. O'Connor and colleagues (26) and Lanigan and colleagues (21) obtained data from parents, and parents and children, over a period of 3 and 5 days, respec-

Table 3. Participant characteristics of misreporters of energy intakes of included studies in the systematic review of the validity of dietary assessment methods used in children (0 to 18 years) when compared with the method of doubly labeled water

Characteristic of child	Reporter	Age (y)	n	Dietary recall method	Status	EI/TEE[a]	*P* value	Reference no.
Sex								
Female	Parent+child	8.3-12.4	11	DHI[b]	AR[g]	0.89	<0.05	31
	Child	15-17	17	DHI	UR[h]	0.82	<0.001	13
	Parent	5-7	31	24-h MPR[c]	AR	1.07	<0.05	24
	Parent	4.2-6.9	23	FFQ[d]	OR[i]	1.62	<0.00	17
	Child	15	25	WFR[e]/EFR[f]	UR	0.78	<0.05	32
Male	Parent+child	8.3-12.4	10	DHI	UR	0.83	<0.05	31
	Parent	4.2-6.9	22	FFQ	OR	1.56	<0.05	17
	Child	15	25	WFR/EFR	UR	0.82	<0.05	32
Weight status								
Overweight	Parent+child	8.3-12.4	16	DHI	AR	0.89	<0.05	31
Obese	Parent+child	8.3-12.4	5	DHI	UR	0.78	<0.05	31
	Child	12-18	28	EFR	UR	0.59	<0.001	19
Ethnicity								
White	Parent+child	11.1-1.7	12	EFR	AR	0.87	<0.06	27
African American	Parent+child	11.1-11.7	11	EFR	UR	0.63	0.002	27
Age								
3	Parent	3	8	DHI	AR	1.13	<0.05	22
9	Parent+child	9	12	DHI	AR	1.06	<0.05	22
12	Parent+child	12	12	DHI	AR	1.13	<0.05	22
12	Parent+child	12	12	WFR	AR	0.89	<0.01	22
15	Parent+child	15	12	WFR	UR	0.78	<0.01	22
18	Parent+child	18	10	WFR	UR	0.73	<0.01	22

[a]TEE=total energy expenditure.
[b]DHI=diet history interview.
[c]MPR=multiple pass recall.
[d]FFQ=food frequency questionnaire.
[e]WFR=weighed food record.
[f]EFR=estimated food record.
[g]AR=adequate report (0.84-1.16 EI/TEE) (13).
[h]UR=under report (<.84 EI/TEE) (13).
[i]OR=over report (>1.16 EI/TEE) (13).

tively. The assisted parental reporting and the shorter reporting period may have improved the accuracy of reports in these two studies.

Taped record of dietary intake, although not a common diet assessment method, has been previously suggested as a future means for assessing dietary intake of children because of convenience, ease of use, the efficiency and the minimal cognitive ability required to use the device (34). However, tape recordings and combination WFRs/EFRs were found to be the most inaccurate methods for assessing EI (100% of participants recording intake using these methods significantly misreported intake; n=30). It is important to note that both studies using these methods (18,31) used data self-reported by children (aged 6.5 to 11 years [18]) and adolescents (aged 15 years [31]). Of the included studies that identified significant misreporting of EI, the FFQ method, which commonly asks respondents to report their usual frequency of consumption of each food from a list of foods for a specific time period, was shown to have a level of misreporting. The FFQ method was used in the study by Kaskoun and colleagues (17), which used parents as a proxy to report dietary intake of children aged 4.2 to 6.9 years, produced the most significant discrepancy between reported EI and measured TEE (OR intake by 59%). Over-reporting using an FFQ was found to be significant in 47% of total child participants (17). FFQs and are known to commonly over-report dietary intake (35); in this study, the over-estimation of EI for children may be attributable to the use of adult portion sizes in the FFQ to estimate each child's intake and the FFQ tool being used was not developed specifically for use with pediatric populations (17). In this review, only two studies were identified that compared DLW to an FFQ and these demonstrated a large degree of variability in their estimation of EI, highlighting just how inaccurate it is. This is consistent with previous reports in adults. For example, the Women's Health Initiative has provided compelling evidence using DLW to demonstrate the inadequacy of the FFQs in capturing energy intake. In general, the FFQ by its design, cannot quantify energy intake reliably (36).

The age of participants was reported for all studies; however, only Livingstone and colleagues (22) directly correlated reporting status to age, whereas EI reported using diet history (interview only) method significantly over-reported intake of children aged 3 to 12 years. This method of assessment produced an accurate measurement of EI for participants aged 15 to 18 years. These findings demonstrate that reporting accuracy using the diet history method in older children and adolescents increases as the child has more input into the data reported and recorded by researchers (22). However, the opposite is true for the weighed food record method; children aged 12 to 18 years were more likely to under-report dietary intake. This agrees with other studies in older children where food records unanimously underreport by 20% with greater bias in older children (37). This may be related to the increased burden associated with weighing all foods for consumption; the participant requiring literacy and numeracy skills; and usual consumption pattern may change due to inconvenience of recording, choice of foods that are easy to record, and beliefs about which foods are healthy or unhealthy (7).

The characteristics of participants found to have misreported intakes suggests that reporting status could be related to ethnicity and weight status that is consistent with other literature (18,38). However, due to the limited number of studies published in this area and available for review, further evidence and research is required in this area.

At the group level, most studies found that the dietary assessment method used in the study was a valid measure of estimating EI; however, it is not as accurate at the individual level. The wide LOA indicate that large variations occur in dietary intakes between individuals. This highlights the need to report energy and dietary intakes using a standardized method to account for variation such as by kilogram of weight status or a standardized EI.

The DLW technique involves dosing individuals with an accurately measured quantity of DLW at baseline and collecting urine samples over a designated period of time, which are subsequently analyzed to calculate TEE (39). The dose of DLW given to each individual is calculated by multiplying a certain quantity of DLW by an individual's body weight or total body water (40) and varies depending on the age of the individual (41). The dosage of DLW administered to the children in the included studies varied in addition to the collection period, which limits the direct comparison between studies difficult. The majority of studies in this review used the method of 24-hour recall that may have contributed to the findings.

The findings of this review are influenced by the limitations commonly associated with the dietary assessment methods. WFRs, EFRs, 24-hour MPR, and tape-recorded intake data all rely on the period of assessment being typical of usual intake and are also associated with recall bias. A further limitation in DLW studies is that the periods of time asessed to capture intake and TEE do not necessarily cover the same time frame. Although the prospective assessment methods such as food records and prospective recalls do capture the typical 2-week DLW time period, this is not the case when retrospective methods such as diet histories or FFQs are administered before the DLW assessment. If subjects have an atypical food consumption pattern, either much greater or lesser, during the DLW urine collection period, this will increase the degree of inaccuracy greatly. Although different studies used the same dietary assessment methods, there are inconsistencies between studies in their implementation. The majority of the studies included a small sample size (<30 participants).

The accuracy of the method may also rely on the reporter of the data. It is difficult to determine from the studies included in this review who is the most accurate reporter of a child's dietary intake and which method is most accurate and reliable. Each study in this review varied in the age of the participants, reporter (parent-reporters, child-reporters, and parent–child reporters were identified in the 15 studies included), and dietary assessment used. It was not possible to accurately determine the relationship of age to reporting status as only one study (22) divided participants according to their ages. However, the results show that when dietary EI is of interest, parents should be used as a proxy for children younger than age 8 years or at least to complement diet information obtained from the child alone, especially when diet methods require more advanced cognitive abilities or the reporting period is a longer time frame (ie, greater than a few days) to improve accuracy of estimated results.

It is important to note that mere participation in a research study may have biased the data reported for each child or adolescent because participants may have selectively reported foods due to their involvement in the study. Reporting methods that required more involvement and, thus, more participant burden (such as WFRs and EFRs) may also result in changes to eating habits or reporting inaccuracies due to the time required and level of difficulty associated with these methods of reporting.

CONCLUSIONS

The review identified 15 studies that have assessed the validity of reported dietary intake against the method of DLW. The limited findings suggest that the 24-hour MPR conducted over at least a 3-day period that includes weekdays and weekend days, using parents as reporters is the most accurate method for reporting EI in children aged 4 to 11 years when compared to TEE measured by DLW. This review indicated that compared to DLW, WFRs provided the best estimates of EI for younger children aged 0.5 to 4 years, while the diet history method provided better estimates for adolescents aged ≥16 years. Further research is needed in this area to substantiate findings.

STATEMENT OF POTENTIAL CONFLICT OF INTEREST: No potential conflict of interest was reported by the authors.

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